

1 We claim:

1. A catheter for emitting x-ray radiation comprising:  
a flexible catheter shaft having a distal end;  
an x-ray unit coupled to the distal end, wherein

5 the x-ray unit comprises an anode, a cathode and an insulator,  
wherein the anode and cathode are coupled to the insulator to  
define a vacuum chamber.

2. The catheter of claim 1, wherein the cathode is a  
field emission cathode.

10 3. The catheter of claim 1, wherein the catheter shaft  
comprises a coaxial cable.

4. The catheter of claim 1, wherein the insulator is  
chosen from the group consisting of beryllium oxide, aluminum  
oxide, or pyrolytic boron nitride.

15 5. The catheter of claim 1, wherein the cathode and  
the anode are coupled to a voltage generator.

6. The catheter of claim 1, further comprising a guide  
wire lumen.

7. The catheter of claim 6, wherein the guide wire  
20 lumen extends partially through the catheter shaft.

8. The catheter of claim 6, wherein the guide wire  
lumen extends partially through the x-ray unit.

9. The catheter of claim 1, further comprising a means  
for centering the x-ray unit within a lumen.

25 10. The catheter of claim 1, wherein the cathode is a  
ferroelectric material.

1 11. An x-ray catheter comprising:  
a flexible catheter shaft for being advanced  
through lumens of the vascular system, the catheter shaft having  
a distal end;

5 an x-ray unit coupled to the distal end, the x-ray  
unit comprising an anode, a cathode and an insulator, wherein the  
anode and cathode are coupled to the insulator to define a vacuum  
chamber.

10 12. The catheter of claim 11, wherein the insulator  
comprises pyrolytic boron nitride.

13. The catheter of claim 11, wherein the anode  
comprises tungsten or platinum and the cathode comprises  
graphite.

15 14. The catheter of claim 11, wherein the cathode is a  
field emission cathode.

15. The catheter of claim 12, wherein the cathode and  
anode are coupled to a voltage generator.

16. The catheter of claim 15, wherein the catheter  
shaft comprises a coaxial cable coupling the anode and cathode to  
20 the voltage generator.

17. The catheter of claim 16, further comprising means  
for centering the x-ray unit within a lumen.

18. A catheter for the emission of x-ray radiation  
comprising:  
25 a flexible catheter shaft having a distal end;  
an x-ray generating unit coupled to the distal  
end, the x-ray generating unit comprising an anode, a cathode and

1 an insulator, wherein the anode and cathode are coupled to the  
insulator to define a vacuum chamber, and

wherein the x-ray generating unit has a diameter  
less than about 4 mm.

5 19. The catheter of claim 18, wherein the x-ray  
generating unit has a diameter of about 1 mm.

20. The catheter of claim 19, wherein the x-ray  
generating unit has a length of about 7 mm.

21. The catheter of claim 18, wherein the x-ray  
10 generating unit has a length less than about 15 mm.

22. The catheter of claim 18, wherein the insulator  
comprises pyrolytic boron nitride.

23. An x-ray catheter for use in irradiating the wall  
of a lumen comprising:

15 a flexible catheter shaft having a distal end;  
an x-ray generating unit; and  
means for centering the x-ray generating unit  
within the lumen.

24. A method for preventing restenosis of a lumen  
20 comprising:

(a) advancing an x-ray catheter through a lumen  
to a first location adjacent an intended site of the lumen,  
wherein the x-ray catheter comprises a flexible catheter shaft  
with a distal end and an x-ray generating unit coupled to the  
25 distal end, the x-ray generating unit comprising an anode, a  
cathode and an insulator, wherein the anode and cathode are  
coupled to the insulator to define a vacuum chamber;

1 (b) causing the emission of an effective dose of  
x-ray radiation to prevent restenosis; and  
(c) removing the catheter.

25. The method of claim 24, wherein step (b) comprises  
5 causing the emission of radiation within a particular energy  
range to achieve a particular depth of penetration.

26. The method of claim 24, wherein the causing step  
(b) further comprises applying a predetermined voltage between  
the anode and the cathode to achieve the particular depth  
10 penetration.

27. The method of claim 24, further comprising irradiating tissue at a rate of about 1-50 grays per minute.

28. The method of claim 27, wherein the irradiating step is conducted for about 1 minute.

15                   29. The method of claim 24, wherein step (b) comprises  
causing the emission of x-rays having an energy of about 8-10  
KeV.

30. The method of claim 24, further comprising centering the x-ray unit within the lumen prior to the step (b).

20                   31. The method of claim 24, wherein the advancing step comprises advancing the x-ray catheter through a lumen of the vascular system through an exchange tube.

32. The method of claim 24, wherein the advancing step  
comprises advancing the x-ray catheter through a lumen of the  
25 vascular system over a guide wire and through a guide catheter.

33. The method of claim 32, wherein a portion of the x-ray catheter is advanced over the guide wire.

1                   34. The method of claim 24, further comprising  
positioning the x-ray unit at a second location and causing the  
emission of x-ray radiation at the second location.

5                   35. The method of claim 24, further comprising  
positioning the x-ray unit at a plurality of locations and  
causing the emission of x-ray radiation at each of the plurality  
of locations.

10                  36. The method of claim 24, further comprising  
conducting an angioplasty procedure prior to step (a), wherein  
the intended site of step (a) is the site of the angioplasty  
procedure.

37. A method for providing x-ray radiation treatment  
comprising:

15                  advancing an x-ray catheter through a lumen to an  
intended site, wherein the x-ray unit comprises a flexible  
catheter shaft with a distal end and an x-ray generating unit  
coupled to the distal end, the x-ray generating unit comprising  
an anode, a cathode and an insulator, wherein the anode and  
cathode are coupled to the insulator to define a vacuum chamber;

20                  causing the emission of an effective dose of x-ray  
radiation; and

                        removing the catheter.

38. The catheter of claim 2, wherein the cathode is  
chosen from the group consisting of graphite, titanium carbide,  
25 carbides, metals, and graphite coated with titanium carbide.

39. The catheter of claim 1, further comprising a  
guide wire lumen extending through the catheter shaft.

1           40. The catheter of claim 2, wherein the cathode  
comprises silicon and the x-ray unit further comprises a grid  
proximate the cathode.

5           41. The catheter of claim 2, wherein the cathode  
comprises silicon needles.

42. The catheter of claim 11, wherein the x-ray unit  
irradiates tissue at a rate of at least about 1 gray per minute.

43. The catheter of claim 1, wherein the anode is  
coupled to a wall of the insulator, wherein the wall is tapered  
10 towards the anode.

44. The catheter of claim 3, wherein:  
the coaxial cable comprises an outer conductor and a  
central conductor;

15 the insulator has a tubular portion with proximal and  
distal ends, the coaxial cable being coupled to the proximal end,  
the anode being coupled to the proximal end and to the central  
conductor of the coaxial cable, and the cathode being coupled to  
the distal end;

20 the catheter further comprises a conductive surface  
surrounding the tubular insulator, coupling the cathode to the  
outer conductor of the coaxial cable; and

25 the insulator and cathode define an annular region  
proximate the coupling between the cathode and the insulator, the  
annular region being screened from an electrical field generated  
between the anode and the cathode by the conductive surface and a  
portion of the cathode.

1                   45. The catheter of claim 44, wherein the insulator  
comprises a wall depending from the proximal end of the tubular  
portion, the wall being angled toward the anode and the vacuum  
chamber.

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